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RESEARCH ARTICLE

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SEISMIC VULNERABILITY OF BUILDING BY CONSIDERING THE EFFECT OF VISCOELASTIC DAMPERS USING PUSHOVER ANALYSIS

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ABSTRACT

An earthquake is the result of a sudden release of energy in the Earth's crust that creates seismic waves. Earthquakes can create serious damage to structures. The structures, already built are vulnerable to future earthquakes. The damage to structures causes deaths, injuries, economic loss, and loss of functions. Earthquake risk is associated with seismic hazard, vulnerability of buildings, exposure. Seismic hazard quantifies the probable ground motion that can occur on site. Vulnerability of buildings is important in causing risk to life.In the present study, analytical investigation of a symmetrical building (SMRF Type) situated in seismic Zone-V of India, in accordance with IS 1893-2002(part-1), is taken as an example and the various analytical approaches (linear static and nonlinear static analysis) are performed on the building to identify the seismic demand and also pushover analysis is performed to determine the performance levels, and Capacity spectrum of the considered, also Base Shear is compared for G+5 and G+11 storey building models in both X and Y directions by using Finite Element Software Package ETAB's 13.0 version.

Key words: Earthquakes, Pushover analysis, Symmetrical building, Performance levels, Capacity Demand and Performance point.

INTRODUCTION

Earthquakes results from the sudden movement of tectonic plates in the earth's crust. The movement takes place at fault lines, and the energy released is transmitted through the earth in the form of waves that causes ground motion many miles from the Epicentre. Regions adjacent to active fault lines are the most prone to experience earthquakes. These waves arrive at various instants of time, have different amplitudes and carry different levels of energy. The size of the earthquake can be measured by Magnitude (M) which was obtained by recording the data of motions on seismograms. This can be measured by an MMI scale (Modified Mercalie Intensity). The Buildings, which appeared to be strong enough, may crumble like houses of cards during earthquakes and deficiencies may be exposed. Experience gained from the Bhuj earthquake of 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of the present day codes.

The seismicity, seismic or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time. Recent research has focused on ways to supplement the damping capacity of earthquake resistant structures. Structures with increased damping will experience decreased elastic response during an earthquake. This reduced response results in less non-structural damage and occupant discomfort. The purpose of this work is to review the work done in these areas by previous researchers. As indicated in the introduction, the focus of this research is on damping systems which use Viscoelastic dampers to achieve high levels of damping.

CURRENT PRACTICE

Currently, FEMA 356 (Prestandard and commentary for the seismic rehabilitation of buildings) andFEMA 440 (Improvement of Nonlinear Static Seismic Analysis Procedures). The focus is on anticipated recommendations to improve inelastic analysis procedures as currently documented in FEMA 356 and ATC 40 serve as the source documents for future design code. Based on performance-based design methodology, FEMA 356 specifies the following procedures in the design for an existing building to be retrofitted by energy dissipation dampers.

- Preliminary design, including sizing of the devices
- Device prototype testing
- Final design of the rehabilitated building to meet the target performance level.

For the performance-based design, a structural analysis is needed to obtain the building seismicperformance. Although there are four analysis procedures specified in FEMA 356 Prestandard, the linear static procedure is the most efficient for preliminary design purpose. To account for the damping from adding VED’s, FEMA 356 specifies a damping modification factor to reduce the seismic effect (pseudo lateral load in a given horizontal direction) on the structure.

METHODS OF SEISMIC EVALUATION

There are different methods of analysis provides different degrees of accuracy. Currently seismic evaluation of buildings can be divided into two categories:

a. Qualitative method

b. Analytical method

QUALITATIVE METHODS

The Qualitative methods are based on the available background information on the structures, past performance of the similar structures under severe earthquakes, visual inspection report and some non-destructive test results, etc.

ANALYTICAL METHODS

Analysis methods are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic methods.

LINEAR STATIC ANALYSIS (EQUIVALENT STATIC ANALYSIS)

In linear static procedures the building is modelled as an equivalent single degree of freedom (SDOF) system with a linear static stiffness and an equivalent viscous damping. The seismic input is modelled by an equivalent lateral force with the objective to produce the same stresses and strains as the earthquake it represents.

This procedure does not in and require dynamic analysis, however, it accounts for the dynamics of building in an approximate manner. The static method is a simplest one; it requires less computational effort and is based on formulae given in code of practice. First, the design Base Shear is computed for the whole building and it is then distributed along the height of buildings. The lateral forces at each floor level, thus obtained are distributed to individual lateral load resisting elements. The procedure generally used for the

Equivalent static analysis is explained below:

(i) Determination of fundamental natural period

(Ta) of the buildings Ta = $0.075*h^{0.075}$ Moment resisting RC frame building without brick infill wall.

Ta = $0.085*h^{0.075}$Moment resisting steel frame building without brick infill walls.

Ta = 0.09*h /√d All other buildings, including moment resisting RC frame building with brick infill walls.

Where,

h - Is the height of the building in meters

d- Is the base dimension of building at plinth levelin m, along the considered direction of lateral force.

(ii) Determination of base shear (VB) of the building

VB = Ah×W

Where,

Ah=Z*I*Sa/2Rg is the design, horizontal seismiccoefficient, which depends on the seismic zone. Factor (Z), importance factor (I), response,reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

(iii) Distribution of design base shear

The design Base Shear VB thus obtained shall be distributed along the height of the building as per the following expression:

Where, Qi is the design lateral force,

Wi is the seismic weight,

Hi is the height of the ith floormeasured from the base and n is the number of stories in the building.

NONLINEARSTATIC ANALYSIS (PUSHOVER ANALYSIS)

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The load is incrementally increased in accordance with a certain predefined pattern. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building frame, plastic rotation is monitored, and a plot of the total Base Shear versus Displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness.

PERFORMANCE OBJECTIVES

A performance objective has two essential parts - a damage state and a level of seismic hazard. Seismic performance is described by designating the maximum allowable damage state (performance level) for an identified seismic hazard (earthquake ground motion). A performance objective may include consideration of damage states for several levels of ground motion and would then be termed a dual or multiple-level performance objective.

The target performance objective is split into Structural Performance Level (SP-n, where n is the designated number) and Non-structural Performance Level (NP-n, where n is the designated letter). These may be specified independently; however the combination of the two determines the overall Building Performance level shown in Fig 1. Structural Performance Levels is shown in the Table 1:

TABLE 1: STRUCTURAL PERFORMANCE LEVELS

PERFORMANCE LEVELS	STRUCTURAL PERFORMANCE	NON-STRUCTURAL PERFORMANCE
Operational (O)	Very light damage. No permanent drift Substantially original strength and stiffness.	Negligible damage.
Immediate Occupancy(IO)	Light damage. No permanent drift, Substantially original strength & stiffness. Minor cracking. Elevators can be restarted. Fire protection operable.	Power and other utilities are available. Equipment's and content secure may not operate due to mechanical.
Life Safety (LS)	Moderate damage. Some permanent drift. Residual strength & stiffness in all stories. Gravity elements function. Building may be beyond economical repair.	Falling hazard. mitigated But extensive system damage.
Collapse Prevention (CP)	Severe damage. Large permanent Drifts. Little residual strength & Stiffness, Gravity elements function. Some exits blocked, Building near Collapse.	Extensive damage

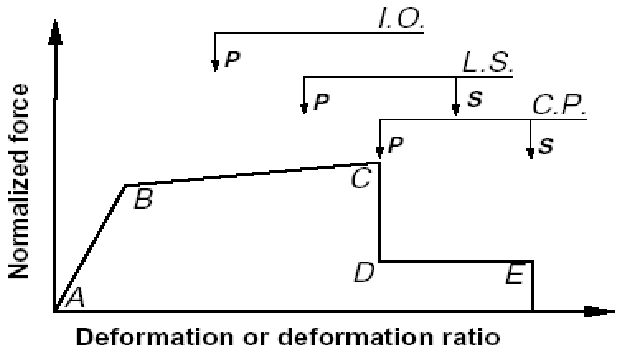

Fig 1: Force Deformation for Performance Levels

The owner, architect, and structural engineer then decide upon the desired condition of the structure after a range of ground shakings, or Building Performance Level. The Building Performance Level is a function of the post event conditions of the structural and non - structural components of the structure.

DESCRIPTIONS OF THE BUILDING CONSIDERED

The structure used in this study is a building of reinforced concrete of 6 storeys with 4 bays along longitudinal direction and 2 bays along transverse direction (Fig.2, Fig.3 and Fig.4.). The beams are of sections 0.4mx 0.5m and the columns are of sections 0.4mx0.7m and the height of each storey is 3m with the thickness of the slab is 125mm. Live load on the roof and slab is 2 kN/m^2 and floor finishes is 1.5 kN/m^2 .Concrete cube compressive strength,f_{ck} = 30 N/mm^2 (M30).Characteristic strength of reinforcing steel, f_y = 415 N/mm^2 (Fe415).Modulus of Elasticity of concrete, E = 27.386 kN/mm^2.Unit weight of concrete = 25 kN/m^3.It is assumed that the inherent damping ratio of the structure is 5%.

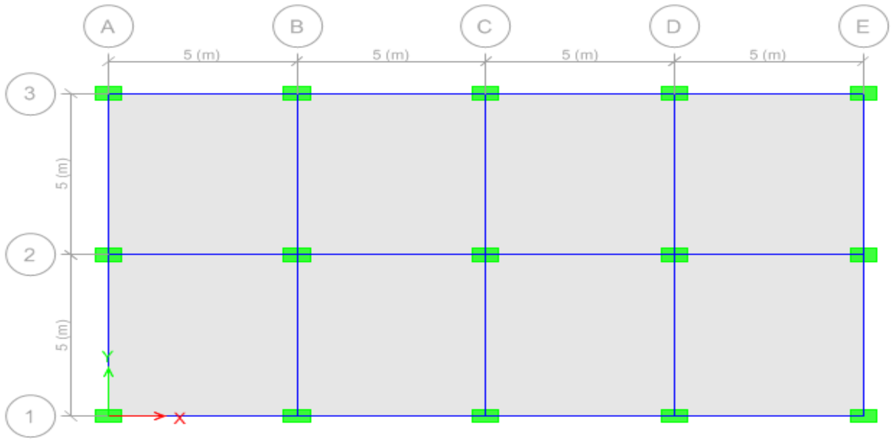

Fig 2: Plan of 6 Storey Building Modelled (from ETABS 13.0)

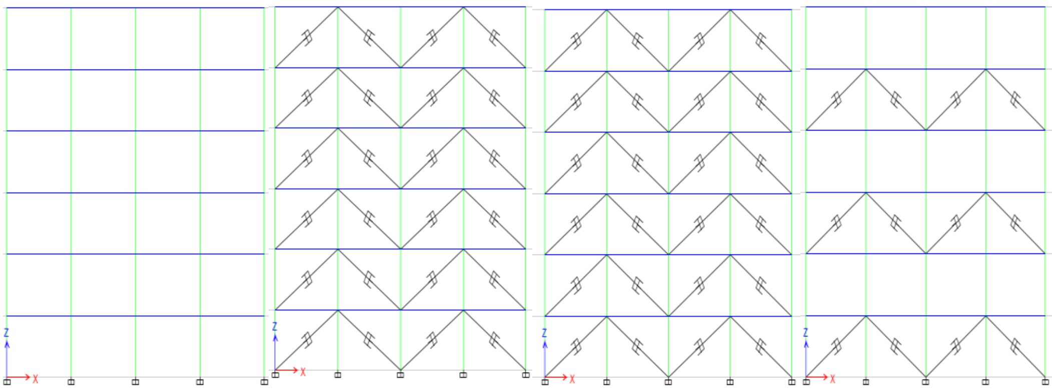

Fig3: Elevation of 6 Storey Building Modelled (a)MODEL 1 - Bare frame (b) MODEL 2 - Building with VED's throughout(c)MODEL 3 - Building with VED's atExternal Periphery (d) MODEL 4 - Building with VED's alternately placed in vertical manner for the storeys along X-X direction (from ETABS 13.0).

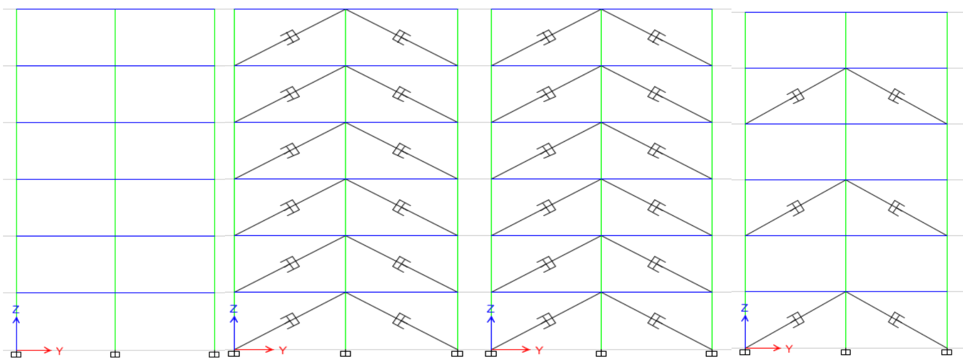

Fig 4: Elevation of 6 Storey Building Modelled (a) MODEL 1- Bare frame (b) MODEL 2-Building with VED's throughout (c) MODEL 3- Building with VED's External Periphery (d) MODEL 4- Building with VED's alternately placed in vertical manner for the storeys along Y-Y direction (from ETABS 13.0).

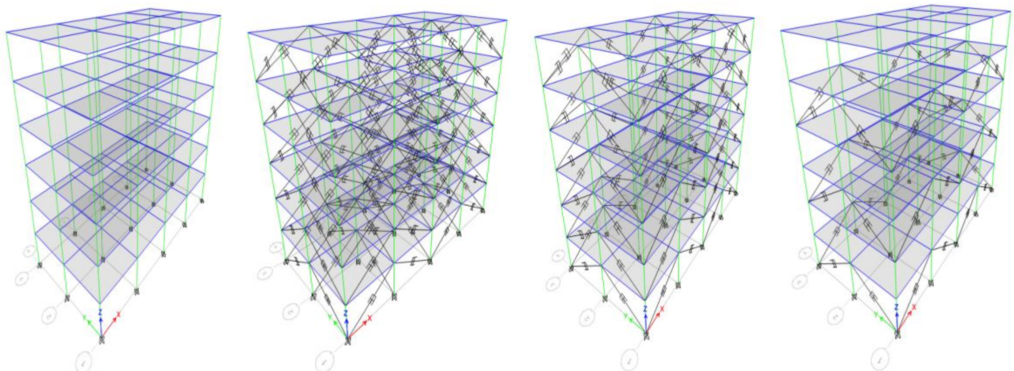

Fig 5: 3-D view of 6 Storey Building Modelled (a)MODEL 1 - Bare frame (b) MODEL 2 - Building with VED's throughout(c)MODEL 3 -Building with VED's External Periphery (d)MODEL 4 -Building with VED's alternately placed in vertical manner for the storeys along Y-Y direction (from ETABS 13.0).

RESULTS AND DISCUSSIONS

Following results are tabulated and graphically plotted for the different parameters.

TABLE 2: Storey Stiffness for G+5 Building Models along Longitudinal direction EQ X

NO OF STOREY	MODEL 1	MODEL 2	MODEL 3	MODEL 4
6	260372.011	8772892.39	7623793.92	681040.39
5	301325.313	13078807	13930075	13633897
4	305123.182	16606030	19916440	1042704.95
3	311360.988	21489530	28614351	28003290
2	346009.222	59931062	52013088	1043801.22
1	628075.825	3.252E+10	1.714E+10	1.204E+10

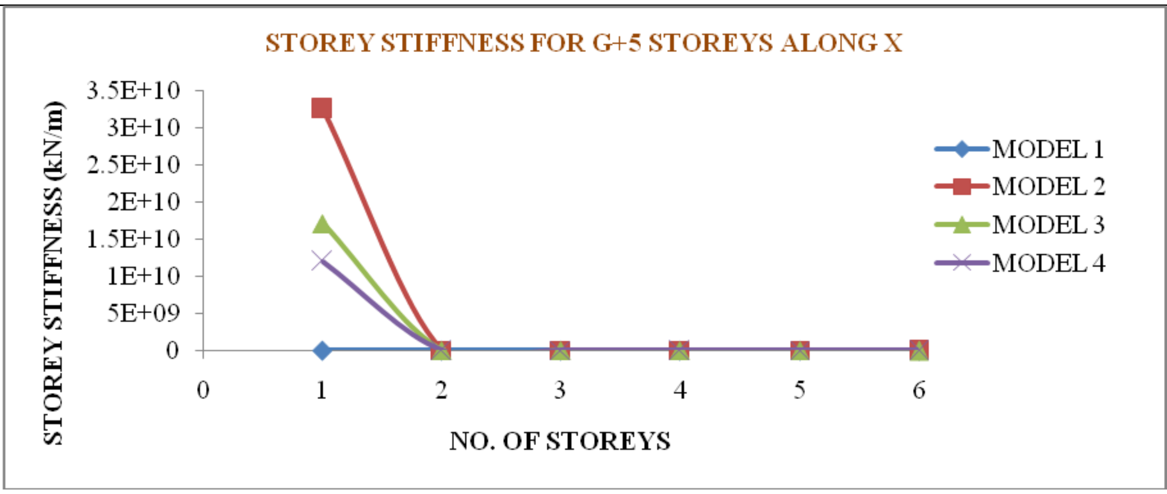

Fig 6: Storey Stiffness profile for SMRF building models in Zone-V at each floor level in longitudinal direction by EQX

TABLE 3: Data for Pushover Curve G+11 Building models in Longitudinal direction PUSHX

SL NO	MODEL	DISPLACEMENT (mm)	BASE SHEAR (kN)
1	MODEL 1 -BARE FRAME	469.6	2514.4158
2		466.8	2565.214
3		463.7	2576.1572
4		378	2463.3824
5		235.9	2267.4442
6		79.2	1983.1193
1	MODEL 2- VED'S THROUGHOUT	25	425916.7069
2		6.5	112740.3465
1	MODEL 3 - VED'S ALONG EXTERNAL PERIPHERY	20.8	13799.699
2		17.5	12943.0057
3		10.7	10147.899
4		6.6	6786.8701
1	MODEL 4 - VED'S ALONG EXTERNAL PERIPHERY ALTERNATIVE	86.5	6974.6337
2		86.5	6974.595
3		86.5	6974.793
4		86.4	6974.5993
5		77.5	6810.3228

TABLE 4: Data for Pushover Curve G+5Building models in longitudinal direction PUSHX

SL NO	MODEL	DISPLACEMENT (mm)	BASE SHEAR (kN)
1	MODEL 1 - BARE FRAME	7.2	768.0976
2		14.4	1536.1952
3		15.7	1676.0398
4		18.4	1886.0956
5		26.4	2175.8845
6		29.6	2272.2949
1	MODEL 2 -VED'S THROUGHOUT	11	56165.4352
2		10.3	54681.2831
3		7.5	42743.9757

1	MODEL 3 - VED'S ALONG EXTERNAL PERIPHERY	15.1	38674.5347
2		11.6	33598.2734
3		11.2	33242.6283
4		10.9	32852.411
1	MODEL 4- VED'S ALTERNATE TO EXTERNAL PERIPHERY TO STOREY	62.7	8889.2007
2		62.7	8843.9842
3		59.7	8805.4758
4		13.8	6713.5756
5		12.3	6555.416

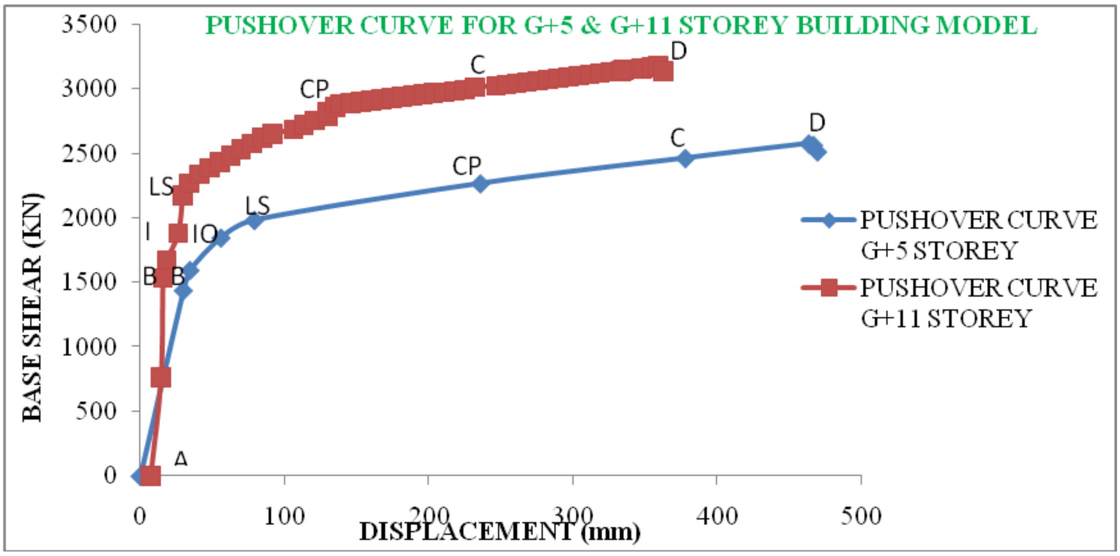

Fig 7:Pushover curve for G+5 and G+11 storey Building models in longitudinal direction PUSHX

Here the Fig.7 shows the obtained pushover curve or capacity curve for G+3 and G+5 storeys models with their performance levels marked in PUSH X direction. In the above Fig.7 the notations indication: A & B-Operational level, IO–Immediate occupancy, LS– Life safety, CP – Collapse prevention, C –Ultimate capacity for pushover analysis, D – Residual strength for pushover analysis.

PLASTIC HINGE: It is a location action on a structural member.

FORMATION OF PLASTIC HINGES: The maximum moments caused by earthquake occur near the ends of beams and columns, the plastic hinges are likely to occur there and most of ductility requirements apply to sections near the junctions.

PURPOSE OF PUSHOVER ANALYSIS

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design of earthquakes by means of static inelastic analysis and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter-storey drift, inelastic element deformations (either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations). The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behaviour. The pushover isexpected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis.

Table 5: Performance levels for G+5 Building Model in longitudinal direction PUSHX

STEP NO	MODEL	FRAME TYPE	HINGE TYPE (kN-m)	HINGE TYPE (kN-m)	HINGE STATE	HINGE STATUS
A	MODEL 1	BEAM	M2	M3		
1			-	0	A to ≤ B	A to ≤ IO
2			-	0	A to ≤ B	A to ≤ IO
3			-	0	A to ≤ B	A to ≤ IO
4			-	0	A to ≤ B	A to ≤ IO
5			-	1.571*10-6	A to ≤ B	A to ≤ IO
B.1		COLUMN	0	-4.084	A to ≤ B	A to ≤ IO
2			0	-8.0908	A to ≤ B	A to ≤ IO
3			0	-8.8339	A to ≤ B	A to ≤ IO
4			0	-10.1778	A to ≤ B	A to ≤ IO
5			1.21*10-6	-14.4094	A to ≤ B	A to ≤ IO

The above Table 5 indicates the range of overall performance level of G+5 storey building model in PUSH X direction which lies in between A to IO.

Table 6: Performance levels for G+11 Building Model in longitudinal direction PUSHX

STEP NO	MODEL	FRAME TYPE	HINGE TYPE (kN-m)	HINGE TYPE(kN-m)	HINGE STATE	HINGE STATUS
A	MODEL 1	BEAM	M2	M3		
1			-	0	A to ≤ B	A to ≤ IO
2			-	0	A to ≤ B	A to ≤ IO
3			-	-54.7	A to ≤ B	A to ≤ IO
4			-	-0.0003	A to ≤ B	A to ≤ IO
5			-	0.0382	A to ≤ B	A to ≤ IO
B.1		COLUMN	0	-6.7153	A to ≤ B	A to ≤ IO
2			0	-7.4554	A to ≤ B	A to ≤ IO
3			2.84*10-6	-9.0458	A to ≤ B	A to ≤ IO
4			-0.0003	-9.8968	A to ≤ B	A to ≤ IO
5			0.0355	-14.8345	A to ≤ B	A to ≤ IO

The above Table 6 indicates the range of overall performance level of G+11 storey building model in PUSH X direction which lies in between A to IO.

Performance Point of the Building using Capacity Spectrum Method

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curves is performance point. Fig 8 shows superimposing demand spectrum and capacity spectrum.

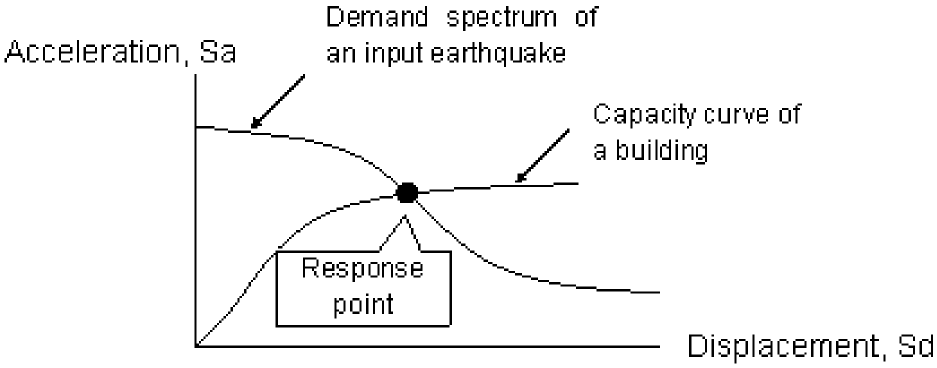

Fig 8: Performance Point of the Building using Capacity Spectrum Method

The Table 7 shows the Data for Performance pointin longitudinal direction (PUSH X) for G+5 storey building models.

Table 7: Performance point for G+5 Storeys Building model along longitudinal direction

STEP NO	MODEL	SPECTRAL DISPLACEMENT (mm)	SPECTRAL ACCELERATION (g)
1	MODEL 1	5.6	0.272850
2		11.3	0.269474
3		12.3	0.265125
4		14.5	0.261869
5		21.1	0.259388
6		23.7	0.252925
7		27.3	0.242693
8		33.2	0.210994
9		39.1	0.187447
10		45.0	0.172173
11		50.9	0.086087

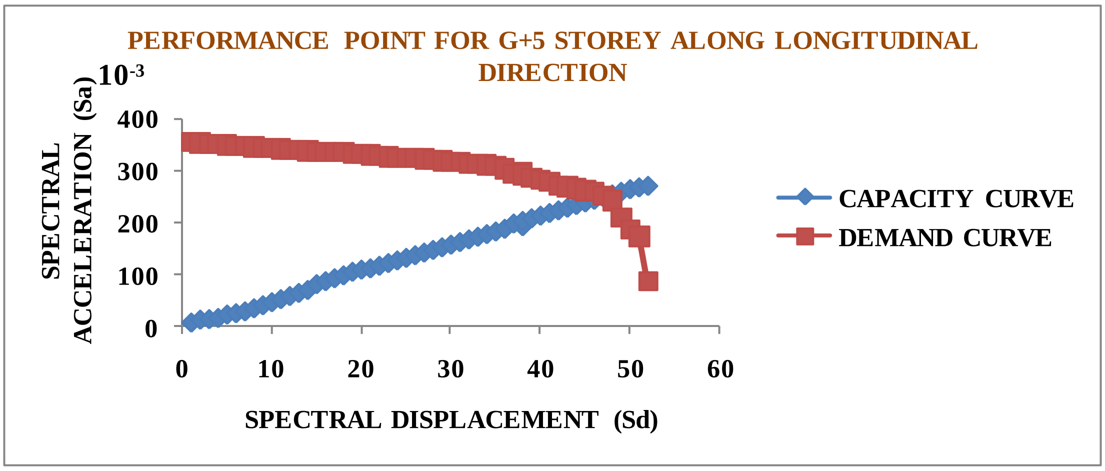

Fig 9: Performance point for G+5 storey building model by combining capacity spectrum model by combining capacity spectrum in Push X direction

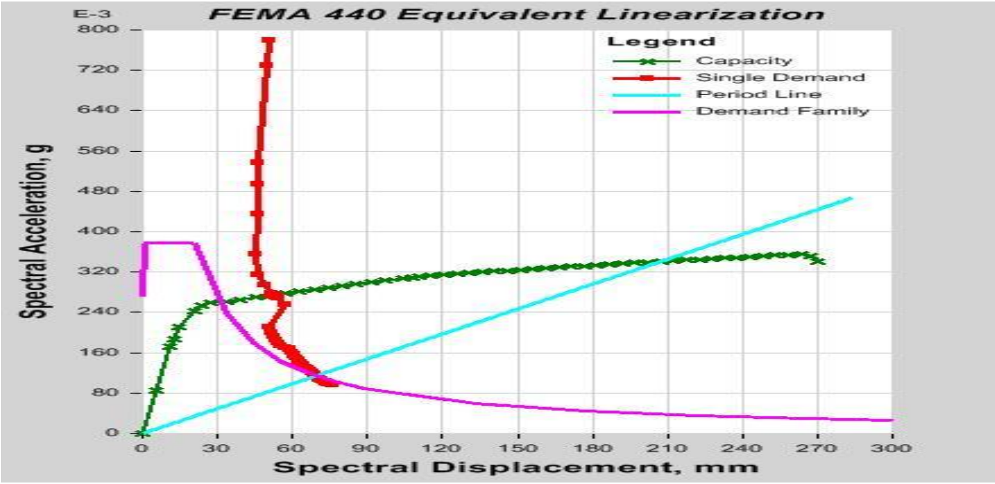

Fig 10: Capacity spectrum for G+5 Building Model along longitudinal direction (from ETABS 13.0)

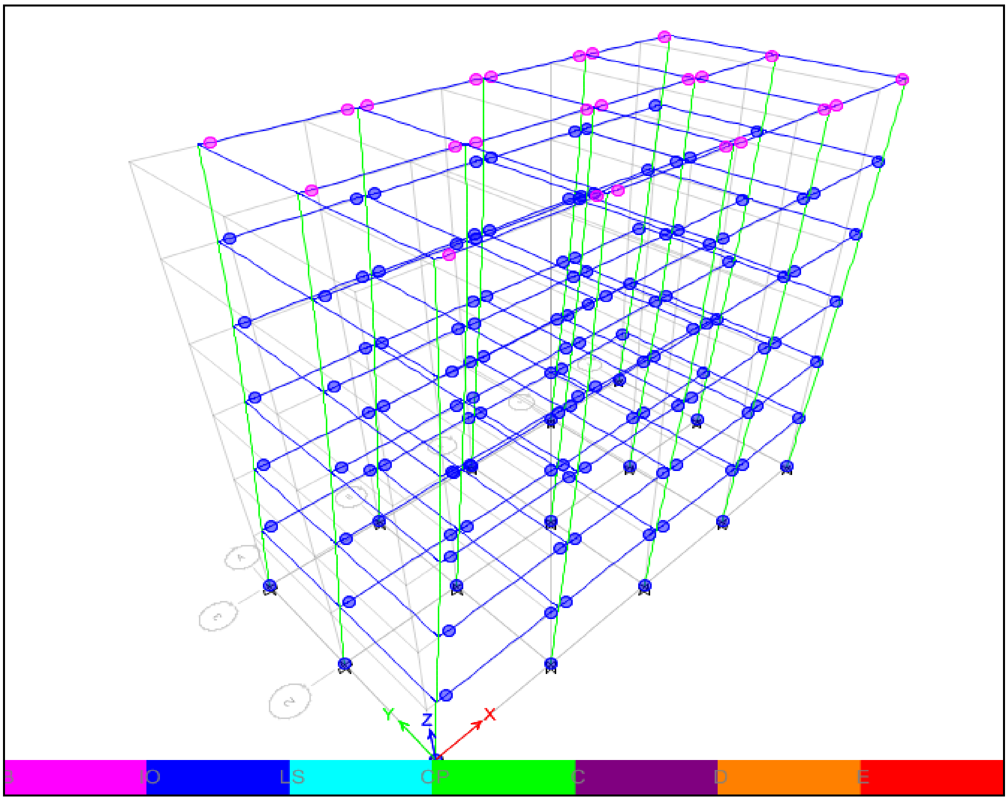

Fig 11: Plastic Hinge Levels Obtained for G+5 storey model along longitudinal direction (from ETABS 13.0)

The above Fig 11shows the location of plastic hinges formed for different performance levels in their final step of analysis for PUSH X direction.

Table 8: Comparison of Base Shear for all two building models in both longitudinal and transverse direction for both equivalent static analysis and pushover analysis

STOREY NOS	MODELS	BASE SHEAR (kN)			
		EQ X	PUSH X	EQ Y	PUSH Y
G+5 STOREY	MODEL 1	807.3855	3137.9805	807.3855	1943.28
	MODEL 2	972.7215	55358.9719	972.7215	57612.57
G+11 STOREY	MODEL 1	967.1842	2557.671	967.1836	1666.346
	MODEL 2	1471.604	422859	1041.0448	1213930

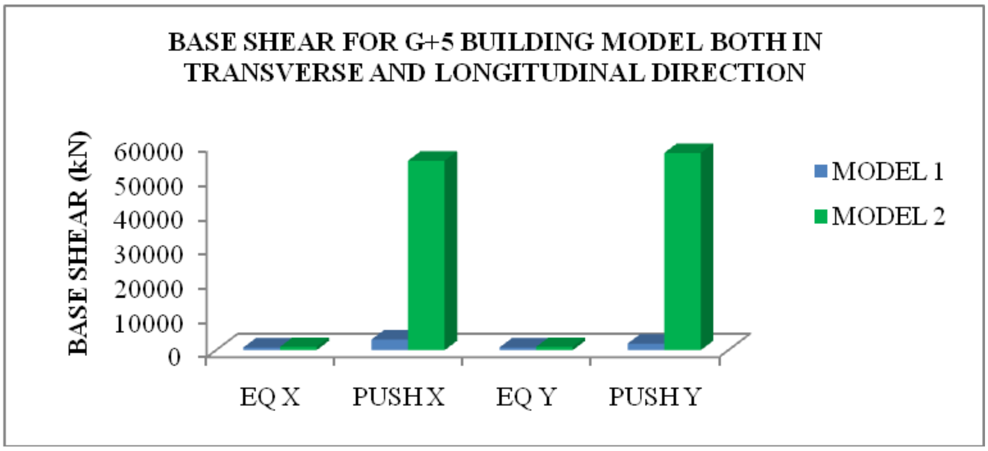

Fig 12: Comparison of Base shear for G+5 building model for both linear static and nonlinear static analysis

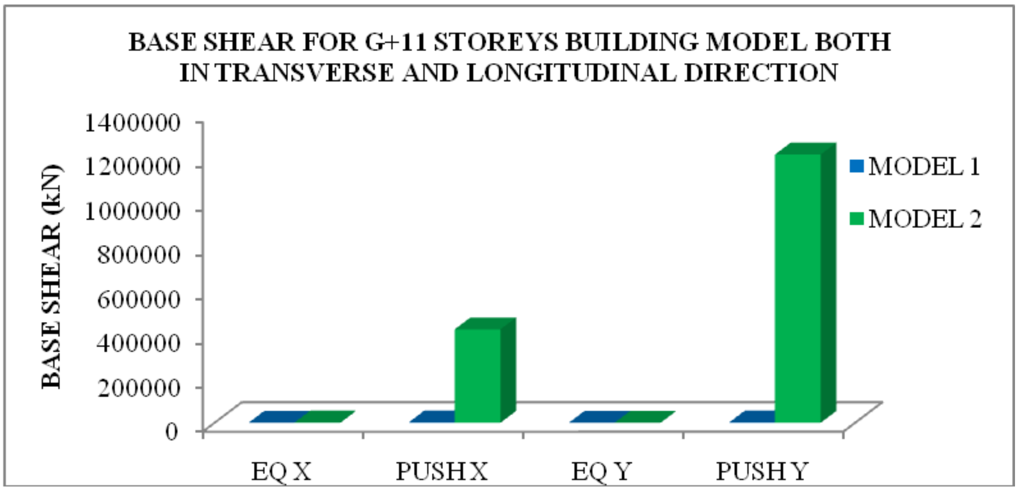

Fig 13: Comparison of Base shear for G+11 building model for both linear static and nonlinear static analysis

CONCLUSION

1. The results obtained in terms of pushover demand, capacity spectrum and plastic hinges gave an insight into the real behaviour of structures.
2. The overall performance level for G+5 and G+11 storey Building Models were found betweenA-IO. The hinge status and location has been determined and it is noted that most of the hinges begin to form in A-IO range.
3. The performance point is determined for G+5 storey Building Models in PUSH X direction at S_a = 0.27448g,S_d = 52.8mm and Shear = 2.5491kN.

4. Base Shear increases with the increase in mass and number of storeys of building; also Base Shear obtained from pushover analysis is nearly thrice for both G+5 and G+11 storey Building Models than the Base Shear obtained from Equivalent Static Analysis.

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